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Effects of Air Flow Rate, Storage Temperature, and Harvest Maturity on Respiration and Ripening of Tomato Fruits

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ABSTRACT

The interactive effects of aeration rate, storage temperature, harvest maturity, and storage duration on respiration and ripening of tomato fruits (*Lycopersicum esculentum* var. Roma) were studied. Slow aeration rate strongly reduced the climacteric but did not affect ripening. Low temperature slowed ripening and reduced respiratory rates, but low temperature did not delay attainment of the climacteric maxima. The effect of air flow rate on the content of CO_2 in the fruits' internal atmospheres was investigated. The possibility that CO_2 is not the primary cause of respiratory inhibition under slow air flow rate is discussed.

In gas flow respirometers the rate at which air is passed over fruit samples may be a critical factor determining their respiration rates (1). In some cases the accumulation of CO_2 is not very great at air flow rates which are inhibitory (1). Claypool *et al.* (2) reported the effects of air flow treatments on the respiration of a number of deciduous fruits. They suggested that an inhibitory effect of CO_2 which accumulated under slow ventilation was responsible for slower respiration.

We have studied the effects of ventilation on respiration and ripening of tomato fruits. The tomato fruit is known to exhibit a respiration climacteric as it ripens (3, 8). In the present study a marked effect of ventilation on the climacteric was found. This effect is relevant to the uncertain role of the climacteric in fruit ripening (1, 10). The present study was extended to fruits of different maturities stored at different temperatures to assure that the ventilation effect was not unique to a particular condition.

MATERIALS AND METHODS

The experiment was conducted with field grown fruits of *Lycopersicum esculentum* var. Roma in a constant air flow respirometer which has been described in detail elsewhere (7). Treatments were arranged in factorial design with the following variables:

2 air flow rates ×	*2 maturities*
10 ml/min	Mature green
40 ml/min	Incipient color

× *2 temperatures* ×	*days of storage*
16 C	16 days
24 C	(See text below)

Two replications were conducted. Each sample (15 fruits, about 1 kg) was enclosed in a 3.78-liter jar with gas flow connections. Rates of CO_2 evolution were determined daily for 16 consecutive days. In preliminary experiments we observed that both O_2 uptake and CO_2 evolution were suppressed by slow air flow rates. The suppressed respiration due to slow air flow rate was not accompanied by a shift in the respiratory quotient. Therefore, only CO_2 evolution was measured as an index of respiration in the present study.

On the 4th, 8th, 12th, and 16th days of storage one sample was removed from each experimental condition for determination of firmness, color, and the concentration of CO_2 in the internal atmosphere of the fruits.

Respiration. CO_2 was determined by gas chromatography. A rubber septum was present in the effluent line, and samples were withdrawn into a gas-tight syringe. The 1-ml samples were chromatographed on a column of 60 to 80 mesh silica gel, 24 inches long and one-fourth inch in diameter. Helium was used as the carrier gas at 13 psi, and the column and thermal conductivity detector were maintained at 130 C. CO_2 production rates were calculated by the formula of Biale (1).

Analysis of Internal Gas Atmosphere. Five fruits from each treatment were removed from the respiratory chamber and immediately submerged under water. A hypodermic needle was inserted approximately 1 cm into the core tissue of the stem scar, and a 0.65 ml sample was withdrawn. Samples of 0.5 ml were analyzed under the same chromatographic conditions previously described.

Other Analyses. Firmness of five fruits was determined with an Asco firmness meter. A 1 kg prestress load was applied for 10 sec, and a stress load of 1.5 kg was applied for 30 sec (6). All 15 fruits of each sample were frozen intact and later thawed and pulped through a 0.028 mesh screen in a laboratory pulper. Color of the deaerated samples was determined with a Gardner color difference meter standardized with a standard having the values: L, 24.1; a, 24.2; b, 11.6. The data were analyzed by statistical methods of Snedecor (13).

RESULTS AND DISCUSSION

Temperature and air flow rate were the strongest variables affecting respiration. Analysis of variance revealed their effects to be independent. All experimental effects were described by two second order interactions: *air flow rate* × *maturity* × *days of storage* and *temperature* × *maturity* × *days of storage*. Certain regression analyses were also conducted.

Effect of Air Flow Rate on Respiration and Ripening. The air flow rates which were used in this study were intentionally quite slow. Especially at the slower air flow rate, the system is never in complete equilibrium. We believe that this does not introduce error of sufficient magnitude to negate the general observations.

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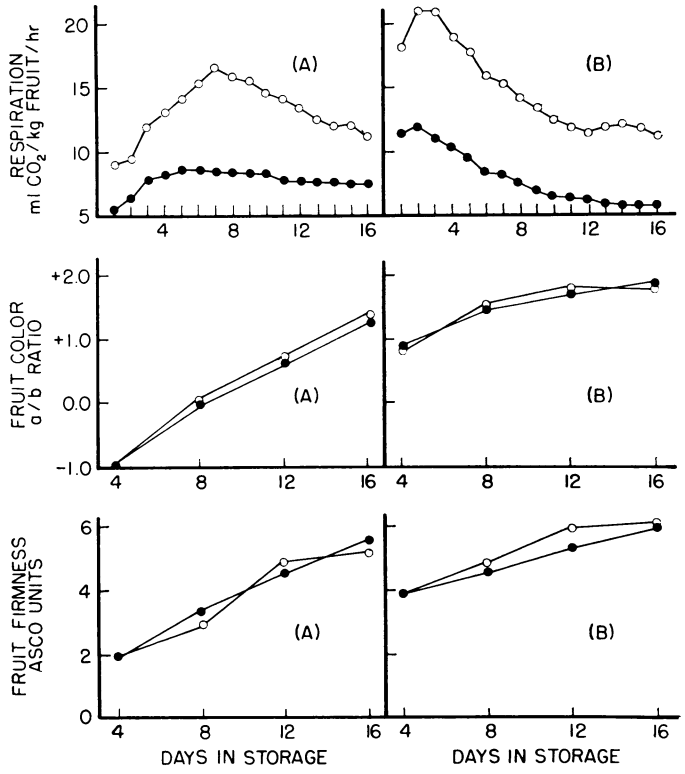

FIG. 1. The effect of air flow rate on respiration, color changes, and softening of tomato fruits. Each datum represents the average behavior for fruits stored at 24 C and 16 C. A: Harvested when mature green; B: harvested at incipient red coloration. ○: 40 ml/min air flow treatment; ●: 10 ml/min air flow treatment.

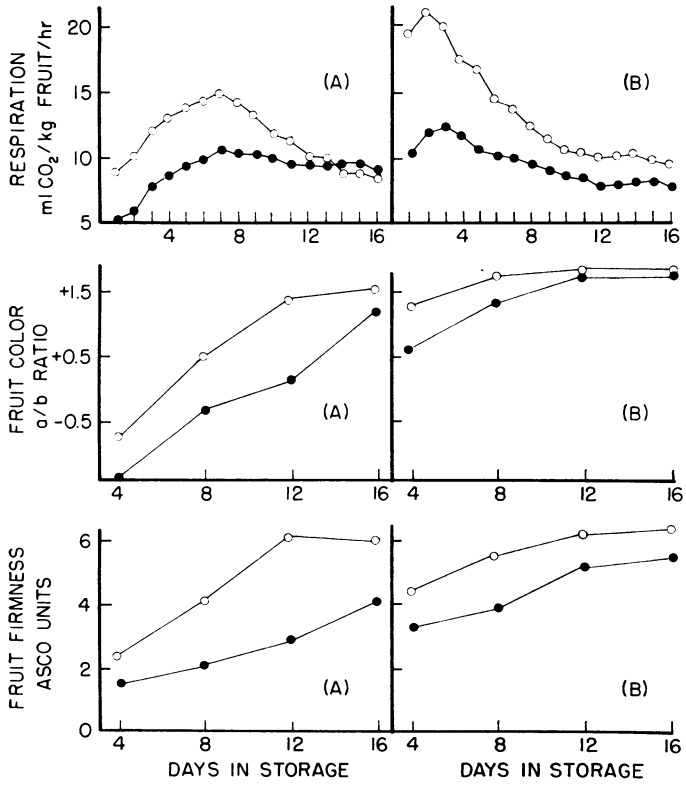

FIG. 2.

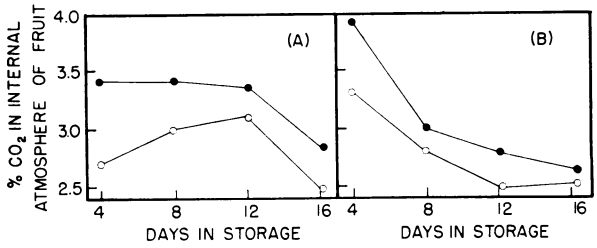

FIG. 3. The concentration of CO_2 in the internal atmosphere of fruits during storage under two air flow rates. Each datum represents the average behavior for fruits stored at 24 C and 16 C. A: Harvested when mature green; B: harvested at incipient red coloration. ○: 40 ml/min air flow treatment; ●: 10 ml/min air flow treatment.

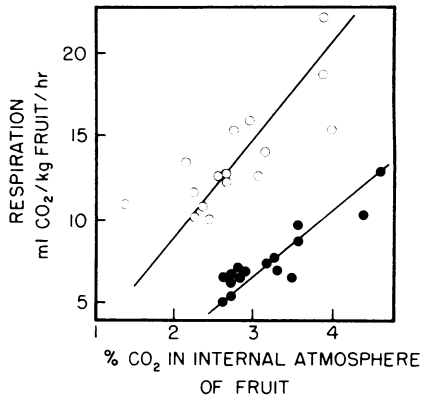

FIG. 4. The regression relationships between respiration rate and internal CO_2 concentration. Each datum represents one experimental condition. ○: 40 ml/min air flow treatment; ●: 10 ml/min air flow treatment.

As can be seen in Figure 1, the slower aeration rate strongly reduced respiration by fruits of both maturities. For mature green fruits at the slower air flow rate the climacteric maximum was reached earlier, and the climacteric was strongly reduced in magnitude. At the 10 ml/min air flow rate, the climacteric consisted of a rise in respiration rate of 2 ml/kg fruit·hr. At the 40 ml/min air flow rate, respiration increased by about 8 ml/kg fruit·hr to the climacteric maximum. Thus, on an absolute respiration basis, the climacteric at the slower flow rate was only about 25% as great as that at the more rapid flow rate for fruits harvested when mature green. Despite the very strong effects of air flow rate on respiration and the climacteric rise, ripening, as measured by changes in color and firmness, was not affected by aeration treatment.

The concept that the climacteric is an integral part of the ripening of fruits originates from the review of Biale (1). One currently held view is that the climacteric is induced by the burst of C_2H_4 production which coincides with ripening (10). A respiratory rise in response to C_2H_4 has been reported in a nonripening tissue, potato tuber (12). Frenkel *et al.* (5) demonstrated that cycloheximide inhibited protein synthesis and ripening of pome fruits. However, the climacteric occurred in the absence of protein synthesis and ripening. The present results are complementary as they suggest that the rate of ripen-

FIG. 2. The effect of temperature on respiration, color changes, and softening of tomato fruits. Each datum represents the average behavior for fruits stored under 10 ml/min and 40 ml/min air flow rates. A: Harvested when mature green; B: harvested at incipient red coloration. ○: 24 C; ●: 16 C.

ing of tomato fruits is not by necessity related to the absolute magnitude of the climacteric. Thus, several lines of evidence suggest that ripening and the climacteric may not be very interdependent processes.

Effect of Temperature on Respiration and Ripening. It is interesting to compare the effect of temperature on time of attainment of the climacteric maxima to its effect on coloration and softening. These data are shown in Figure 2. When fruits of either maturity class were stored at 24 C, maximal coloration was obtained by the 5th or 6th day after the respiratory maxima. However, when fruits were stored at 16 C, maximal color values lagged behind the respiratory peak by 9 or more days. The same trend is evident when the softening data are compared to the respiratory curves. Thus, slower coloration and softening at 16 C were not accompanied by delayed attainment of the climacteric maxima. These data indicate that metabolic changes which underlie ripening of tomato fruits are not strictly correlated with the time course of the climacteric. A parallel to these results may be seen in the data of Dostal and Leopold (4). They observed that tomato fruits treated with GA were markedly delayed in their ripening when compared to nontreated fruits. However, the climacteric was not delayed at all by GA treatment.

Differences in respiration rates due to temperature diminished toward the end of the storage period. After the climacteric, respiration declined rapidly at 24 C, but very slowly at 16 C.

It is evident from the air flow data and temperature data that fruits which were harvested when mature green did not achieve as high respiratory maxima as fruits which were harvested at inception of red color. The same trend for higher respiratory maxima as fruits are harvested closer toward maturity is evident in data of Lyons and Pratt (8) for individual fruits.

CO_2 Content and Respiration. In Figure 3 the patterns for CO_2 concentration in the fruits' internal atmospheres are shown for both maturities and air flow rates during storage. Fruits held under the slower ventilation rate contained more CO_2 in their internal atmospheres. Thus, the possibility exists that the slightly expanded pool of CO_2 at the slower air flow rate served in the sense of a feedback inhibitor on respiration. However, strong inhibitions of mitochondrial reactions have been observed only at CO_2 concentrations which are considerably higher than those which existed in the present study (9, 11). More relevant are the studies of Young *et al.* (14) on the effects of O_2 and CO_2 levels on the climacteric of intact fruits of several species. Their data show a marked delay of the climacteric in the presence of 10% O_2 and 5% CO_2 compared to air controls. This effect is quite different from the effect of slow air flow rate on the climacteric which we have noted here.

With regard to the possible inhibitory effect of CO_2, it is of interest to examine another relationship between the fruits' internal CO_2 contents and respiration rates. In Figure 4, respiration rates and internal CO_2 contents of fruits have been correlated for all experimental conditions. This relationship was greatly modified by air flow rate. Higher respiration rates were associated with higher internal CO_2 contents under either air flow rate. Clearly, from these data it may be seen that respiration rates of fruits held at the 10 ml/min air flow rate were strongly inhibited compared to fruits held at the 40 ml/min air flow rate when their internal CO_2 contents were equal. This observation is not consistent with the idea that the higher internal CO_2 content at the 10 ml/min air flow rate is the primary responsible factor for the slower respiration rate.

It may be that the present effect of ventilation on respiration is not related to O_2 deficiency or to CO_2 accumulation. It is possible that some unrecognized volatile which has a production rate that is not proportional to respiration accumulates under conditions of slow aeration and inhibits respiration. Additional studies are needed to evaluate fully the effects of ventilation treatments.

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